2.3 Earthquakes

Figure C2.21: The Four Seasons Apartments in Alaska collapsed during the earthquake of March 27, 1964. The building was under construction and unoccupied.

Geologists think intense earthquakes and volcanoes frequently occurred in Alberta hundreds of millions of years ago. No one was around to observe these ancient events, so if you really want to know what earthquakes are like, you need to observe the effects of earthquakes in modern times.

Around supper hour on the evening of March 27, 1964, most people in Alaska were already home from work or on their way home. Since this day was also Good Friday, the start of the Easter holiday, many businesses had closed early. College students had already left to go home for the holiday, and most highrise office buildings were empty. All these factors proved to be lifesavers because, at 5:36 p.m., the second-largest earthquake ever recorded by a seismograph occurred.

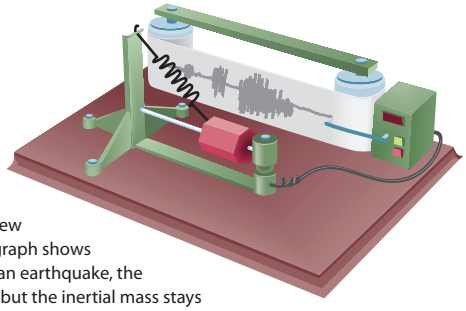


Figure C2.22: This simplified view of a seismograph shows that during an earthquake, the base moves but the inertial mass stays still and a recording of the motion is made on the paper. The paper is fed at a constant speed.

Earlier in this chapter, you learned that when searching for petroleum in subsurface rock formations, man-made explosions can create seismic waves that can be recorded by a seismograph. In the case of The Alaska Earthquake of 1964, the seismic waves were so intense that a seismograph in Alaska that was attempting to record the event literally went off the chart.

The energy released by this earthquake was so intense that Earth vibrated like a gigantic planetary bell. The ringing triggered effects that were felt around the world. The next day, farmers in both Alberta and Saskatchewan noticed changes in the height of their well water. Similar effects were later reported from places as far away as South Africa.

Most property damage occurred in the coastal areas of Alaska closest to the actual location where Earth's tectonic plates suddenly moved. The city of Anchorage suffered the greatest amount of property damage—about 30 blocks of office buildings and apartment buildings were destroyed. Most schools were severely damaged. For example, the Government Hill Grade School was completely destroyed by one of the many landslides that resulted from the three minutes of violent ground shaking.

As you will learn later in this lesson, underwater landslides proved to be particularly devastating due to the huge water waves they generated in both bays and fjords.

What caused this earthquake? How did seismic waves carry this energy to other parts of the planet? The 1964 earthquake measured 9.2 on the Richter scale. What does this number mean? How is it determined? In this lesson you will answer these questions. The answers will form important background information for the next parts of Chapter 2, as you return to events within Alberta and study the processes responsible for the formation of the Rocky Mountains.

Practice

15. Use the information from this lesson and Lesson 1.1 to define the following terms.
    a. crustal plate
    b. plate tectonics
    c. seismic wave
16. Why do urban areas usually suffer the greatest loss of life as a result of earthquakes?

- fault: a crack in Earth's crust due to the motion of one tectonic plate relative to another
- subduction: the downturning of oceanic crust under another crustal plate

Causes of The Alaska Earthquake of 1964

The Alaska Earthquake of 1964 was caused by the motion of the Pacific Plate relative to the North American Plate. The boundary between these two crustal plates is called a **fault**. The Pacific Plate is made of dense oceanic crust, so it tends to be pushed under the less dense continental crust of the North American Plate.

This process is called **subduction**. As a result of this subduction, the continental crust that made up most of southern Alaska was compressed and warped by the huge pressures between these two plates. The stress caused the rock to deform or change shape by bending. Energy was stored in the deformed areas in the form of elastic potential energy, much like when a spring is compressed. When the stress became greater than the breaking strength of the rock, a break occurred in the fault. The stored energy within the misshapen plate was suddenly released.

The stress between the two plates was relieved on March 27, 1964, when portions of southern coastal Alaska could no longer withstand the strain and suddenly moved to the southeast over the Pacific Plate. On average, the total distance moved was about 9 m. This sudden motion of the lithosphere caused seismic waves to be sent out. This transferred energy from the lurching crust to other points on Earth's surface.

During The Alaska Earthquake of 1964, the seismic waves originated from the initial breaking point along the fault (called the **focus**), which was a region 25 km below Earth's surface. Prince William Sound, located approximately 120 km east of Anchorage, was the place on Earth's surface directly above the earthquake's focus, so it was called the **epicentre**.

- focus: the region that first breaks along a fault during an earthquake
- epicentre: the point on Earth's surface directly above the focus of an earthquake

In "Utilizing Technology: Subduction," you can view an applet on the Science 20 Textbook CD to see how the process of subduction can lead to earthquakes.

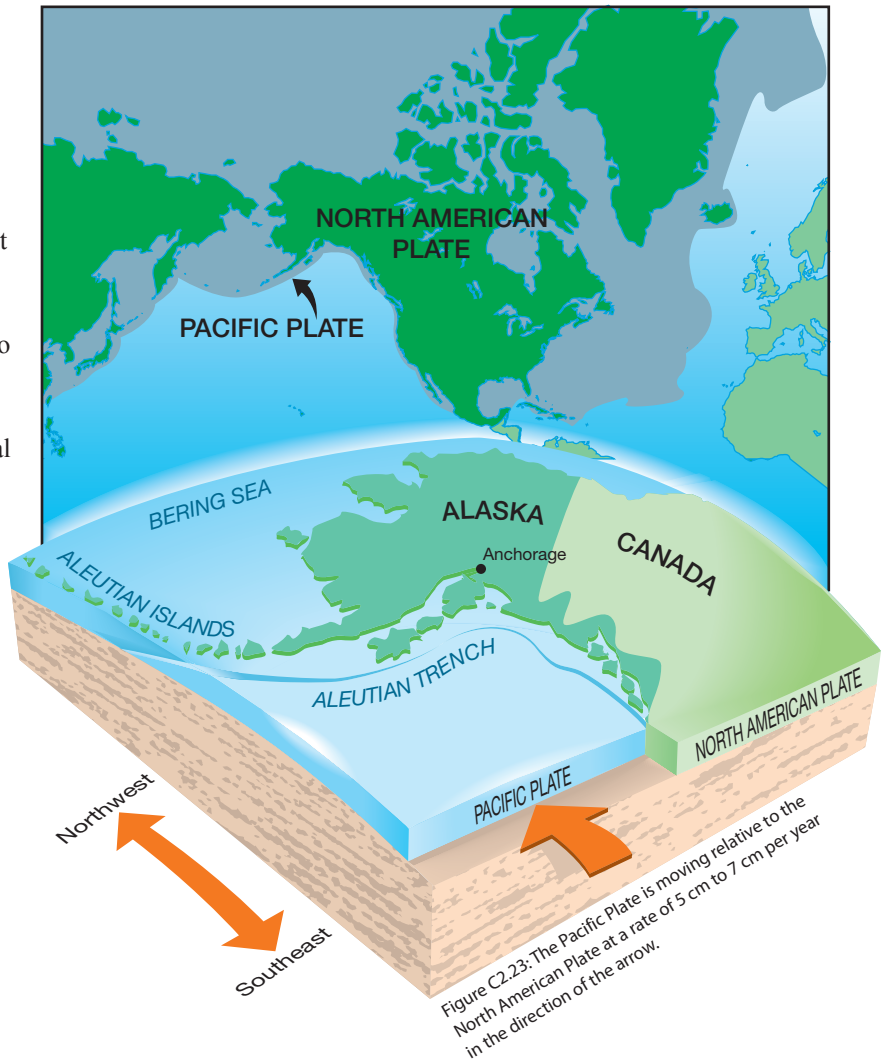


Figure C2.23: The Pacific Plate is moving relative to the North American Plate at a rate of 5 cm to 7 cm per year in the direction of the arrow.

Utilizing Technology

Subduction

Purpose

You will watch the applet "Subduction" that animates a similar process to the subduction of the Pacific Plate under the North American Plate, which caused the famous 1964 earthquake. The analysis questions will allow you to apply the information presented in this lesson to the process shown in the applet on the Science 20 Textbook CD.

Science Skills

- ✓ Performing and Recording
- ✓ Analyzing and Interpreting

Analysis

Use Figure C2.24 to answer the next two questions.

The following labels have been omitted from the diagram: fault, focus, epicentre, lithosphere, asthenosphere, seismic waves, oceanic crust, and continental crust.

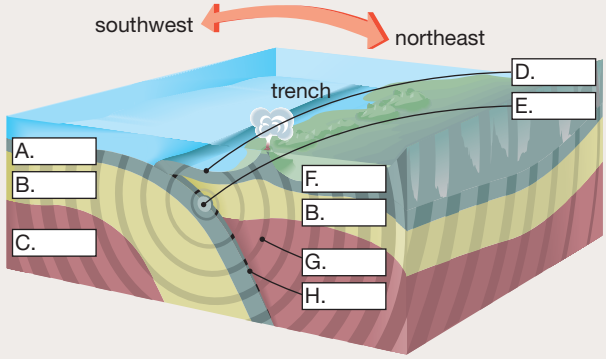


Figure C2.24: This diagram outlines an earthquake's focus and epicentre.

1. Correctly match each label on the diagram with its correct box in Figure C2.24.
2. Recall your work with the rock cycle in Chapter 1.
   a. Identify the type of rock (sedimentary, igneous, or metamorphic) you would expect to find at the point labelled E.
   b. Concisely explain what happens to the oceanic crust as it descends into the mantle.
   c. Use your answer from question 2.b. to concisely explain why it is quite likely that the mountains shown in Figure C2.24 are volcanically active.

Types of Seismic Waves

So that energy released at the focus can reach the surface, seismic waves have to transfer the energy through the subsurface rock. One way for seismic waves to transfer energy is through **primary waves**, which are often called **P-waves** for short.

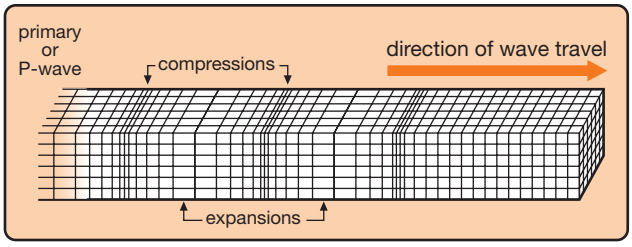


Figure C2.25: P-waves are also known as primary waves.

As the name suggests, the primary or P-waves are the first to arrive because they travel the fastest. As these waves travel through the rock, the matter is alternately compressed and then expanded. Since P-waves are like an extremely low-frequency sound wave, they are able to travel through solids, liquids, and gases.

Another way that seismic waves can transfer energy is through **secondary waves or S-waves**.

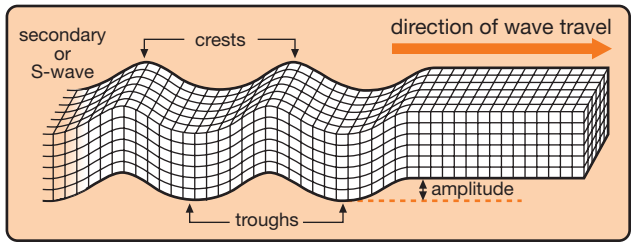


Figure C2.26: S-waves are also termed secondary waves.

S-waves move slower than P-waves and can only move through solid rock. In an S-wave the rock vibrates up and down—or left and right—as the wave moves forward. As a result, S-waves cause the rock to change shape without changing volume. Since liquids and gases do not resist a change in shape (liquids and gases flow instead), S-waves cannot pass through liquids and gases. S-waves have a larger **amplitude** and, therefore, transfer more energy than P-waves.

- primary wave or P-wave: a seismic wave that travels through rock as a series of compressions and expansions of particles
  A P-wave is able to pass through solids, liquids, and gases.
- secondary wave or S-wave: a seismic wave that travels through rock as a series of crests and troughs
  An S-wave can pass through solids but not liquids or gases.
- amplitude: the maximum displacement of a wave from the rest position

Investigation

Modelling Seismic Waves with a Spring

Purpose

You and your partners will use a large-diameter spring (a Slinky) to generate waves that model P-waves and S-waves. You will also have an opportunity to observe the connection between spring properties and the speed of the wave that travels through the spring.

Science Skills

- ✓ Initiating and Planning
- ✓ Performing and Recording
- ✓ Analyzing and Interpreting
- ✓ Communication and Teamwork

Materials

- metre-stick
- stopwatch
- large-diameter spring (for example, a Slinky)

CAUTION!

Don't overstretch the spring. Overstretching may cause the spring to become permanently deformed. Don't suddenly release one end of the spring when it's stretched. The recoiling spring may strike and injure your partners.

Procedure

step 1: Model a P-wave. Generate a P-wave by thrusting your hand—which is holding the spring—back and forth toward the other end of the spring. You can tell if this is being done correctly because the spring will remain in a straight line. There will be little sideways motion. The main motion should be the compression travelling down the spring.

step 2: Repeat the previous step until all members of your group have a chance to generate the model of the P-wave.

step 3: Record a sketch of your model of a P-wave. Be sure to include labels for compressions and expansions.

step 4: Model an S-wave. Have two members of your team stretch the spring out several metres across a hard-surfaced floor. Have one partner hold his or her end of the spring still while the other partner moves the end of the spring to the left and to the right at a steady rate. Adjust the rate of hand motion so the wave clearly shows crests and troughs.

step 5: Repeat step 4 until all members of your group have an opportunity to generate the model of an S-wave.

step 6: Record a sketch of your model of an S-wave. Be sure to include labels for crests and troughs.

step 7: Design a simple procedure to measure the speed of a model S-wave when the spring is stretched to its safest maximum length. Concisely record your method.

step 8: Record your measurements and calculations in an appropriate format.

step 9: Repeat steps 7 and 8 when the spring is only stretched to half of its maximum length. Record your results.

Observations

1. Record your labelled sketch of a model P-wave.
2. Record your labelled sketch of a model S-wave.
3. Record the procedure used to determine the speed of a wave.

Calculations

4. Record the data and calculations for the speed of the S-wave when the spring is at its safest maximum stretch.
5. Record the data and calculations for the speed of the S-wave when the spring is at one-half the length of its safest maximum stretch.

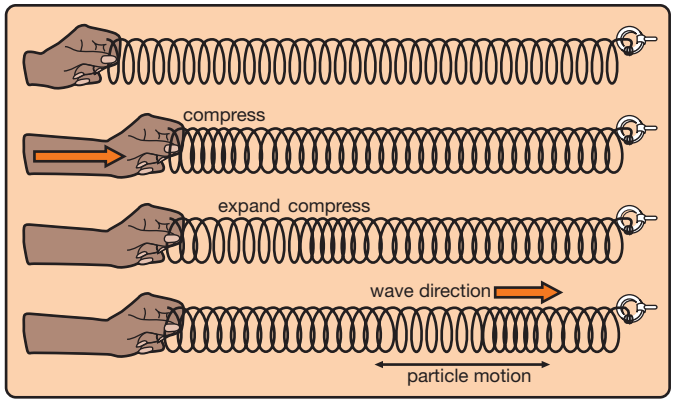
Evaluation

6. Share the results of your calculations with other student teams.
   a. Compare your speed values with those of other groups. How do you account for any differences?
   b. Compare your procedure for determining velocity with the methods devised by other groups. If you had to repeat this activity, what improvements would you incorporate?

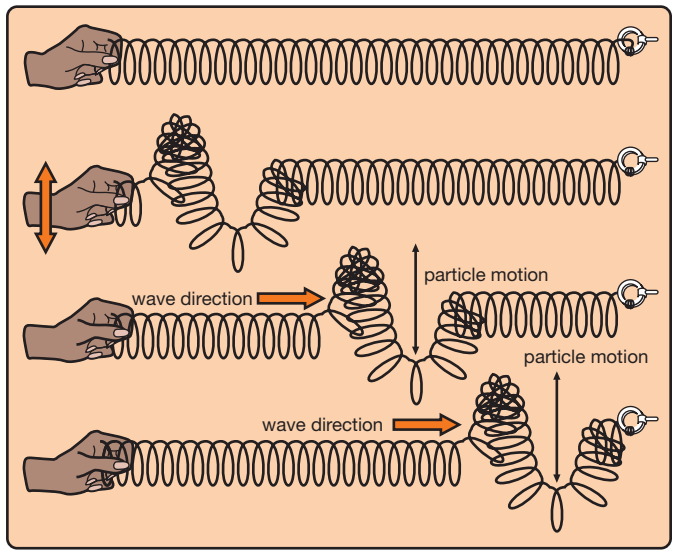
In "Modelling Seismic Waves with a Spring," you created a model of P-waves by moving your hand in a direction parallel to the direction the wave was moving. This is why a P-wave is classified as a **longitudinal wave**. When you created a model of S-waves, your hand moved in a direction perpendicular to the direction the wave was moving. It is for this reason that an S-wave is classified as a **transverse wave**.

- longitudinal wave: a wave in which the vibration of the particles is parallel to the direction the wave is travelling
- transverse wave: a wave in which the vibration of the particles is perpendicular to the direction the wave is travelling

P-Wave Model



S-Wave Model



P- Waves, S-Waves, and Earth's Interior

In "Modelling Seismic Waves with a Spring," you observed that changing a property—like the tension in a spring—influences the speed of a wave that travels through that spring. In Chapter 1 you learned that Earth is comprised of a number of layers. These layers have different properties, such as density, temperature, and pressure, that all increase as you move from Earth's crust to its inner core. If you combine the results of the investigation with this idea, it is reasonable to suppose that seismic waves should travel at different speeds as they pass through different layers of Earth's interior. Geologists have found evidence to support this.

As depth increases, the speed of both P-waves and S-waves increase. Sudden changes in rock properties cause the waves to quickly change direction. This is similar to light waves bending as they enter a lens. This sudden change in direction causes a region where P-waves from an earthquake cannot be detected; this region is called a P-wave shadow zone. Researchers concluded that the P-wave shadow zone could be explained if Earth's centre were composed of different material than the mantle.

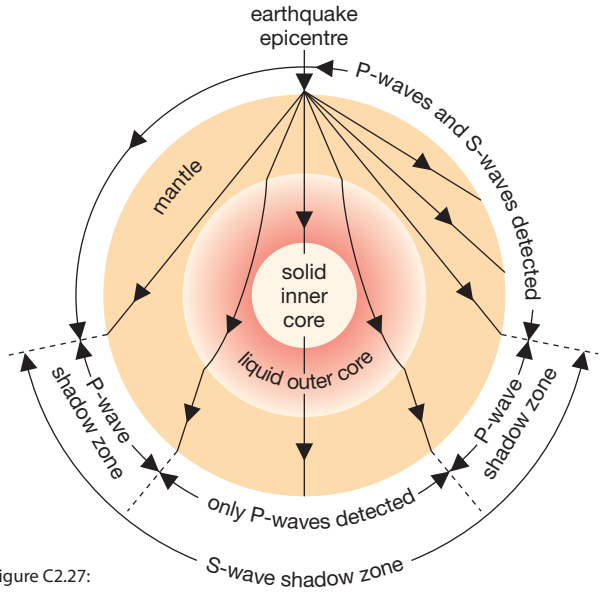


Figure C2.27:
Shown are the changes in direction of seismic waves as they pass through Earth. The sudden change of properties at the mantle/core boundary causes the P-waves to bend.

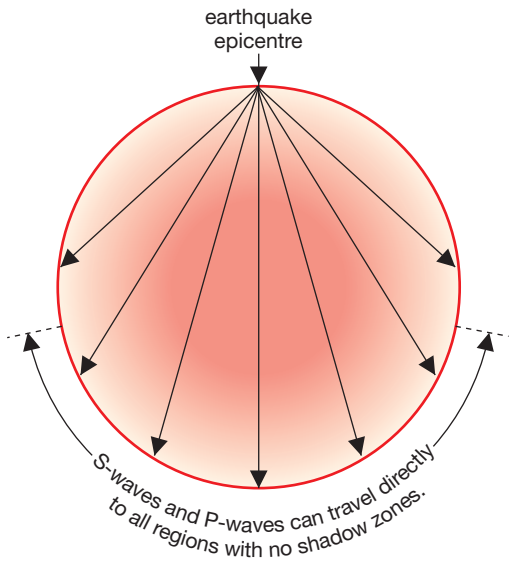


Figure C2.28: An imaginary Earth with a completely solid interior of uniform composition would have no shadow zones.

If you look carefully at Figure C2.27, you will see a region on the side of Earth opposite the earthquake epicentre where only P-waves are detected. There is a much larger region called the S-wave shadow zone where no direct S-waves are received. What could prevent S-waves from travelling directly from the earthquake through the planet's centre? The simplest explanation is that the outer portion of the core must be liquid, since S-waves do not move through liquids. If Earth had a uniformly solid composition from its crust to its centre, both P-waves and S-waves would move in straight lines at a constant speed, as in Figure C2.28. Therefore, there would be no bending and no shadow zones.

Surface Wave Examples

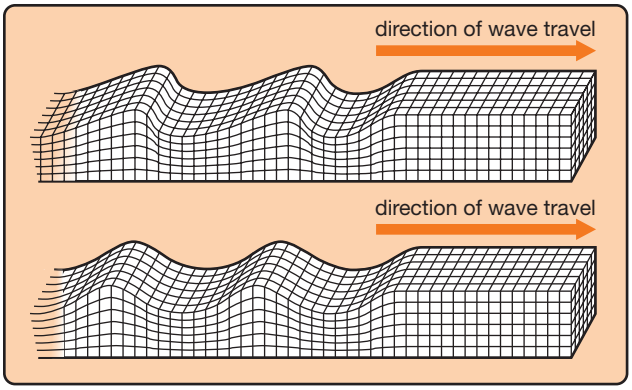


Figure C2.29: Surface waves move along the surface of Earth's crust.

Surface waves do not travel through the interior of Earth, but they do move along the surface of Earth's crust. The motion of surface waves is more complex than P-waves or S-waves.

As a surface wave moves along the ground, it causes the ground to move, much like a water wave will move a boat up and down. Surface waves will also move the ground from side to side, similar to an S-wave. Surface waves do not travel far from the epicentre, and they travel slower than S-waves.

The "Properties of Seismic Waves" table summarizes the properties of types of seismic waves.

PROPERTIES OF SEISMIC WAVES

Property	Primary Waves	Secondary Waves	Surface Waves
range of speeds (km/s)	6 to 14	3 to 8	1 to 6
mode of vibration	longitudinal: particles vibrate parallel to wave velocity by creating compressions and expansions	transverse: particles vibrate perpendicular to wave velocity by creating crests and troughs	complicated combination of transverse and longitudinal vibrations
transmitting materials	solids, liquids, and gases	solids only	mainly through solids
part of Earth transmitting type of wave	all parts of Earth—atmosphere, lithosphere, mantle, and core	the lithosphere and mantle only	top layer of Earth's crust in upper lithosphere
effects during an earthquake	• first wave to arrive • perceived as abrupt thud	• second wave to arrive • causes first period of ground rolling • more damaging than P-waves	• last waves to arrive • responsible for most of ground shaking • cause most damage because buildings can only withstand minimal shaking

Practice

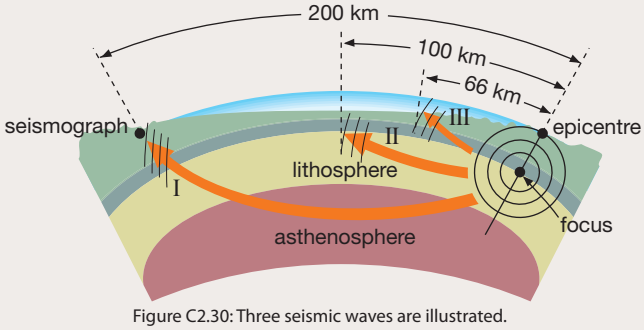


Figure C2.30: Three seismic waves are illustrated.

Refer to Figure C2.30 to answer questions 17 and 18. It shows three seismic waves—labelled I, II, and III. It also shows the distance travelled by these waves from the focus of an earthquake after 20 s. These waves are all eventually detected and recorded by the seismograph located 200 km away from the epicentre.

17. Assume that all three waves travel 200 km from the focus to the seismograph.
    a. Calculate the speed of waves I, II, and III.
    b. Use your answer from 17.a. to determine the type of wave that corresponds to each wave.
    c. The energy of a seismic wave is indicated by the amplitude of the signal recorded by the seismograph. The maximum amplitude of wave III is indicated as A_3 on Figure C2.31. Relate two reasons why wave III is more likely than waves I and II to damage buildings at the seismograph's location.
18. Refer to your answers for question 17. Determine which of the waves could travel directly to a seismograph on the completely opposite side of the planet from the epicentre.

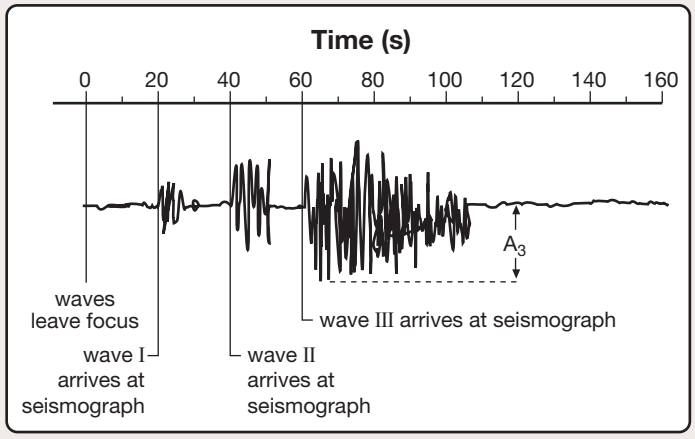


Figure C2.31: A seismogram is an earthquake record obtained by a seismograph.

Studying Earthquakes Using Seismic Waves

Although surface waves produce the most damage in an earthquake, most geologists are more interested in P-waves and S-waves—these waves can travel through Earth and provide a lot of information about its internal structure. Although they were generically referred to as seismic waves earlier in Chapter 2, the waves that geologists generate to look for petroleum in subsurface rock are, in fact, P-waves.

One of the most common applications of P-waves and S-waves is locating an earthquake's epicentre. In questions 17 and 18, you saw how the S-waves lag behind the P-waves. This is due to the lower speed of the S-waves.

The time difference between the arrival of S-waves, as compared to P-waves, provides a method of locating the distance between the seismograph and the epicentre. The farther away from the epicentre, the greater the time difference between the arrival of the P-waves and S-waves. This principle is similar to two runners, where the faster runner will always reach the finish line first. But the longer the race, the greater the time difference between the arrival of the two runners.

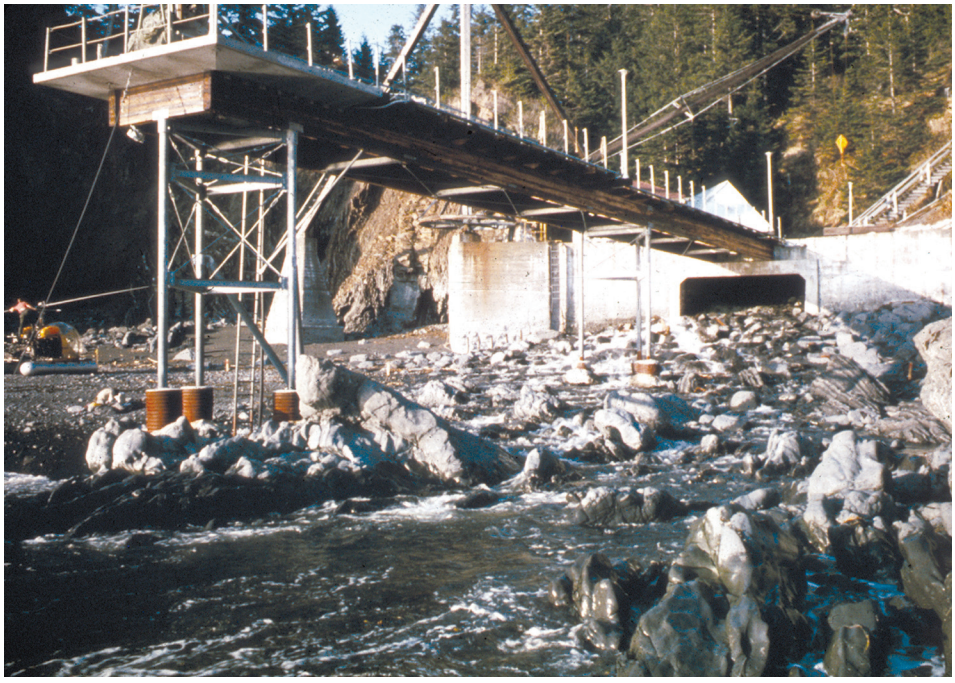


Figure C2.32: This United States Coast Guard dock was drastically altered after The Alaska Earthquake of 1964. It was raised more than two metres above the high-tide mark.

The time interval between the two waves can also be used with other values to determine the **Richter magnitude** of an earthquake. The Richter magnitude is useful for both categorizing and comparing earthquakes. An earthquake with a Richter magnitude of 3.0 is barely detectable by people. The Alaska Earthquake of 1964 had a Richter magnitude of 9.2, second only to the 9.5 magnitude of the Chilean earthquake of 1960. Earthquakes with larger magnitudes may have occurred prior to the development of the Richter scale.

Richter magnitude: a number assigned to an earthquake based upon the amount of vertical ground motion at its epicentre

"Earthquake Analysis" on page 350 uses an applet that illustrates the key points in both finding the epicentre and determining the Richter magnitude of an earthquake.

Utilizing Technology

Earthquake Analysis

Science Skills

✓ Performing and Recording
✓ Analyzing and Interpreting

Purpose

You will locate the epicentre of an interactive earthquake by using the applet titled "Earthquake Analysis" on the Science 20 Textbook CD. You will also have an opportunity to calculate the Richter magnitude of the virtual earthquake by using your data.

Preparation

This application is completely self-contained and is quite user-friendly. It would be very helpful to have access to a printer. You will want to print key documents to not only record your progress but also provide study materials to prepare for tests.

Work through the application according to the instructions. To create a record of your progress, print the following key documents:

- the seismograms that allow the measurement of the S-wave and P-wave intervals
- the tables for calculating distance to the epicentre
- a map that shows the triangulation to find the epicentre
- the seismograms that allow the measurement of the S-wave amplitudes
- a table (nomogram) for determining the earthquake's Richter magnitude

Check for Understanding

1. Outline the basic steps to determine an earthquake's epicentre by using data from three different seismographs. Answer in the form of a flowchart.
2. Concisely explain why the amplitude for the S-wave measured by a seismograph is a smaller value at a seismic station located farther away from an earthquake's epicentre.

Tsunamis

Although it was a victim of The Alaska Earthquake of 1964, the fishing boat in Figure C2.33 was not carried to the centre of the town of Kodiak by earth movement. This damage was done by a **tsunami**, which is sometimes incorrectly called a tidal wave. The sudden movement of the sea floor that occurred as the Pacific Plate moved under the North American Plate caused a series of enormous seismic sea waves.

tsunami: a seismic sea wave set off by an earthquake in or near an ocean basin

Most of the damage and loss of life from this earthquake was due to the resulting tsunami that moved down the Pacific coast of North America and across the Pacific Ocean.

Figure C2.33: This boat was damaged by a tsunami in 1964.

On December 26, 2004, the strongest earthquake since The Alaska Earthquake of 1964 occurred 255 km off Sumatra's coast in the Indian Ocean. Like the Alaska earthquake, this was a large earthquake—with a Richter magnitude of 9.0—caused by one tectonic plate being subducted under another. This generated a powerful tsunami.

However, in this case, the tsunami hit densely populated areas in South Asia and East Africa. Hardest hit were parts of Sumatra, Indonesia, and India's Nicobar Islands. In total, approximately 300 000 people lost their lives in this tragedy.

Tsunamis and First Nations People

The oral traditions of the Pachena people from northern Vancouver Island suggest that an earthquake and the large tsunami that followed destroyed a village. This was described by Chief Louis Clamhouse in 1964.

> They had practically no way or time to try to save themselves. I think it was at nighttime that the land shook . . . . I think a big wave smashed into the beach. The Pachena Bay people were lost . . . .

The oral traditions of other First Nations people recall a time when Earth shook for days, whales were found in the forest, and landslides buried entire villages. Many geologists regard these stories as accurate oral accounts of an earthquake that occurred on the west coast of Vancouver Island on January 26, 1700, at about 9:00 p.m. How could scientists deduce the time of this event? The arrival of the resulting tsunami ten hours later was accurately recorded in the historical records of fishing villages all along the east coast of Japan.

Using this data and other evidence, geologists suspect that the quake probably originated off the coast of Vancouver Island. You can learn more about the Cascadia Megathrust Earthquake of 1700 in the Chapter 2 Review Questions.

2.3 Summary

Earthquakes occur due to the sudden release of stored energy. This energy builds up over time due to the motion of crustal plates. When the energy is released, one plate suddenly moves relative to another—this causes seismic waves to travel through the surrounding rock. Primary waves, or P-waves, travel the fastest, so they are the first to arrive at some other point on Earth's crust. Secondary waves, or S-waves, arrive next and these tend to cause more damage than P-waves. Although they do not travel as far as primary waves and move at relatively low speeds, surface waves tend to do the greatest damage during an earthquake. The difference in the arrival times of P-waves and S-waves can be used to determine the location of the epicentre of the earthquake if data from at least three seismographs is available. This information can also be combined with the maximum amplitude of the S-wave to determine the Richter magnitude number of the earthquake.

2.3 Questions

Knowledge

1. Sketch two diagrams to illustrate the differences between S-waves and P-waves.
2. Identify which type of seismic wave produces the most damage in an earthquake.
3. Explain why it is incorrect to say that the seismic waves produced by an earthquake start at its epicentre.

Applying Concepts

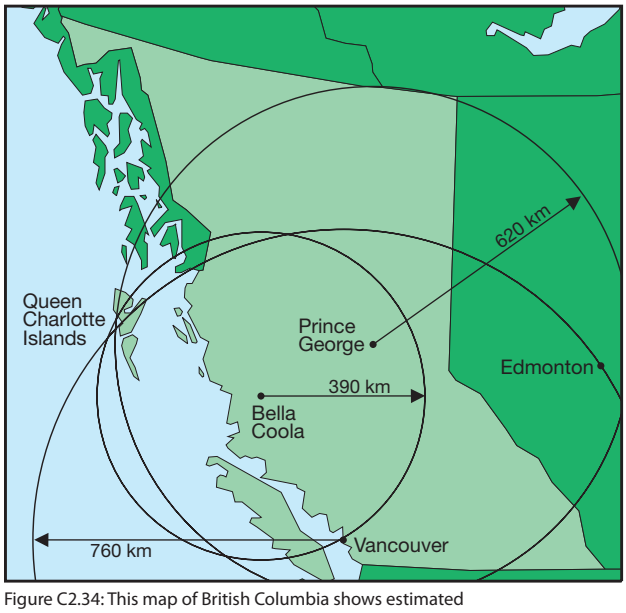


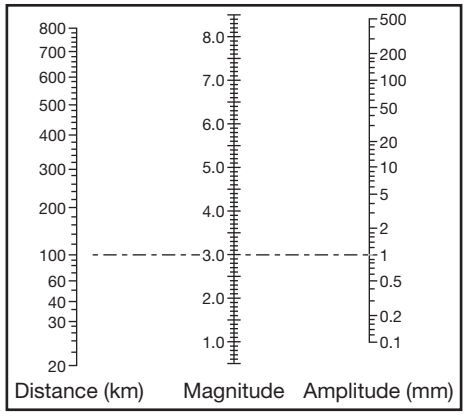
Figure C2.34: This map of British Columbia shows estimated distances to an earthquake's epicentre.

4. Figure C2.34 shows the estimated distances to the epicentre of an earthquake for three seismographs. Use the map to determine the epicentre of this earthquake.
5. Refer to Figure C2.34. The three seismograph stations shown on the map recorded the following data.

Seismograph Station	S-P Interval (s)	Distance to Epicentre (km)	Maximum Amplitude of S-wave (mm)
Vancouver	77	760	9
Bella Coola	40	390	140
Prince George	63	620	20

Use this data and the "Richter Magnitude Chart" to determine the Richter magnitude for this earthquake.

Richter Magnitude Chart



6. Concisely explain why the maximum amplitude of the S-wave is larger in Bella Coola than it is in Vancouver, even though the seismographs are measuring the same earthquake.
7. Internet Search: The largest earthquake recorded by seismographs in Canada had its epicentre in the same location as the fictional earthquake described in questions 4 to 6. Use the Internet to research answers to the following questions.

   a. Identify when Canada's largest earthquake recorded by a seismograph occurred.
   b. What was the Richter magnitude number for this earthquake?
   c. Concisely describe the cause of this earthquake in terms of the motion of tectonic plates.
   d. Explain how you located information to answer the other parts of question 7. Identify the search strategies used and how much time you needed. Compare your strategies and results with other students. How could you have improved your approach to more efficiently find the information?